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Load capacity assessment of bridges
Transport Infrastructure
There is an increasing demand to understand the capacity of structures on road and rail networks.

The demand is driven by increasing loads and ageing infrastructure that is deteriorating, causing asset owners to worry about the ongoing safety of their structures.

Fortunately, there is a range of methods of assessing structures that can be used to assist the asset owners in understanding the risks. Along with the range of methods, however, comes cost, so it is important to gain an understanding of the options available and their complexity and benefits to ensure that value for money is obtained without inadvertently compromising safety.

This paper reviews the methods available, their complexity and relative cost to help bridge asset managers understand the options available to them.

1. Introduction
Over the years bridges have been designed to various and increasing design loads reflecting the increasing demands on the road network. Over 100 years ago the predominant form of transport was the horse and cart, and foot traffic. The heaviest loads at those times were those of steam rollers used in road construction, weighing in the order of 15 tonnes. With the advent of petrol engines, the ability of vehicles to haul heavier loads has increased such that there are now road trains hauling in excess of 100 tonnes.

To reflect current usage and possible increases of loading for the next 100 years the current bridge design code, AS 5100, provides SM1600 loading. The SM1600 design load was formulated on the basis that lane widths and vertical clearances are relatively fixed and the materials that are transported are generally only packed to a certain density. Based on SM1600 loading it is unlikely that there will be a need to increase design loads for quite some time.

To ensure the safety of bridge infrastructure, asset owners need to understand the capacity of their bridges accounting for current condition and the demands from the current vehicles using those assets.

Load capacity assessment should be undertaken in a structured manner by experienced bridge engineers. In Victoria, the state road authority VicRoads released the Road Structures Inspection Manual which in part details this process. VicRoads requires consultants to be prequalified to PE level for these works. By using appropriately qualified firms, asset owners minimise their risks and are most likely to achieve value for money by avoiding unnecessary strengthening or inadvertently leaving a structure in use that may have too high a risk associated with it.

Because of the importance of load rating existing structures a specific section (Part 7) was added to the bridge design code AS 5100. This section of the code introduced a tiered approach to load rating acknowledging that there is a cost-benefit assessment required to determine the appropriate approach.

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The following levels of assessment, in order of complexity, are outlined by AS5100.
1. Theoretical analysis.
2. Analysis using the results of field investigation.
3. Test loading in the field or in the laboratory.

2. Theoretical analysis
Theoretical analysis can be undertaken by two main methods: a generic assessment and using the rating equation. A generic assessment is by far the cheapest form of assessment due to the speed at which it can be undertaken.

2.1 Generic assessment
A generic assessment is undertaken by comparing a rating vehicle’s design action to what is believed to be the original design actions. The capacity of the structure is assumed to be consistent with the original design vehicle which may or may not be the case. For example, the structure may have been overdesigned in the first instance or, since construction, it may have deteriorated and lost capacity. Generic assessments are a good starting point for an asset owner to understand what may be critical on their network if they do not have complete load rating information for their assets.

2.2 Rating equation
AS 5100 provides a rating equation that can be used to assess structures and determine a structures rating factor for a nominated rating vehicle. The rating factor is obtained by calculating the theoretical capacity of a structure and the design actions for the nominated rating vehicle.

A rating factor of 1 or more indicates that the structure has sufficient capacity to support the nominated vehicle with the code-specified load and reduction factors. Rating factors less than 1 indicate that there is a deficiency. Even though there may be a deficiency it doesn’t mean that a bridge would necessarily collapse under the nominated load due to the inherent and justified conservatism of the code. The conservatism is often overlooked by inexperienced asset owners who don’t understand why certain vehicles may be able to pass over a structure in practice, even though an engineering assessment has indicated a rating factor less than 1.

2.2.1 Determining appropriate vehicles for the rating
When undertaking a load assessment, it is important to use appropriate vehicles in the assessment. For example, it would not be appropriate to assess a bridge designed for a steam roller in the late 1800s for SM1600 loading as the design load has no relevance to the structure. A more appropriate assessment would be to use an A or B class loading which better reflects the structure’s intended capacity. In addition to choosing a load consistent with the original design loading it is also appropriate to check the structure for current vehicle load configurations such as GML and HML vehicles.
By checking a structure for its original design load or presumed design load based on its age a subsequent load assessment can be used to determine if the structure was appropriately designed. The bridge engineer needs to consider changes in design codes that have occurred over time to interpret the results. For example, the design codes have changed from working stress to limit state design. The net effect is that structures with a high self-weight may be deemed to carry slightly more load than when originally assessed. Conversely provisions have changed for the shear assessment of structures and when assessments are now undertaken on some structures to their original design loads they are found to be deficient to current codes.

3. Analysis using the results of field investigation

When an assessment is undertaken, consideration should be given to the condition of the structure. As a structure deteriorates the likelihood of it losing capacity to carry loads increases. To assess the effect of deterioration, a load assessment should be undertaken in both the ‘as is’ and ‘as new’ condition states.

To get an appropriate understanding of the ‘as is’ capacity, field inspections are used. An initial assessment may be undertaken by using the results of a level 2 inspection but ultimately an inspecting engineer needs to quantify the extent of deterioration as it relates to the structural capacity. For example, an engineer will pick up the amount of rusting and location of rusting in steel members for later use in structural analysis. A level 2 inspection may only pick up that rusting is occurring without quantifying its extent.

3.1 Level 2 inspections

A level 2 inspection report can be used as the starting point in determining the scope of inspection that may be required by an engineering inspection. It is also useful for identifying similar types of structures on a network. By identifying similar structures, the performance of the group of structures may be better understood.

Level 2 bridge inspections, done in accordance with TMR, RMS or VicRoads inspection manuals, generally do not obtain sufficient information for as is’ load assessments. The manuals have been written in an attempt to balance the cost of inspection to the detail and accuracy of the inspection.

Currently, level 2 inspections do not need to be undertaken by bridge engineers, although the inspectors shall have the backing of one. With advances in inspection technologies and asset management systems it is likely that more detailed information will be collected by more experienced inspectors in the future.

3.2 Engineering inspections

Engineering inspections can be used to obtain information about existing structures. For example, if design drawings have been lost an experienced bridge engineer may be able to inspect the bridge and provide advice on the capacity of the bridge based on their understanding of the designs that were in use at the time. To determine whether a structure conforms to a particular standard, further investigation is generally required.

The extent of investigation depends on the type of structure but often includes measuring the geometry of members for comparison with drawings or where drawings are not available to determine the geometry of the structure for structural analysis.

If the founding conditions are unknown, then geotechnical testing may be undertaken to confirm founding conditions. This may involve the use of a backhoe or hand-held equipment at relatively low cost for shallow foundations, or the use of boreholes for piled foundations. If boreholes are used they should be recorded by the asset owner for future use in designing any replacement structure.

3.2.1 Timber bridge investigations

Investigations for timber bridges require the assessing engineer to understand the basic geometry of the bridge structure, including span lengths, pier heights and structural members’ cross-sectional properties.

Non-destructive testing may be undertaken, such as sounding, stress wave—based testing or boring. Sounding of members is mainly applicable to small members or where near-surface defects are suspected. Wave-based testing is relatively inexpensive with many brands of testers available for purchase from America. Care needs to be undertaken to understand local timbers to avoid erroneous results.

Dackermann et al. (2013) provides some good information about its use and limitations.

Boring provides very good information about the quality of the timber and its state of deterioration. To minimise the potential of damage by boring to members, probing of old boreholes is a good low-cost alternative. Moreover, if boring is undertaken at sites known to be most susceptible to decay then preservative treatments may also be applied.

Ultimately, asset owners need to understand that once members are placed in unprotected environments, timbers will decay. Australian Standards give the estimated life of timbers in those environments and this information can be used to understand the likely level of deterioration. Engineering inspections can then be used to determine the likely remaining life, and scope bridge repairs or replacements.

Most asset owners have determined that it is a false economy to maintain timber bridges and are only doing so if the bridges are of heritage significance or until they obtain sufficient capital for their replacement. The Victorian state road authority, VicRoads, now only has a handful of timber bridges on its network.

3.2.2 Metallic structures

Engineering inspections involve the measurement of key dimensions, including the cross-section of steel elements.

For very old steel structures, the type of metal may be unknown and for these structures it is appropriate to take coupons from the structure to determine their composition (e.g. steel, cast iron or wrought iron).

For most metallic structures, an engineering inspection can then be used to determine the load capacity of the structure because all of the relevant information to undertake an assessment is available. One difficulty, however, is assessing fatigue damage as the loading history is often not well understood. An assessment, however, can highlight critical areas of the structure for more detailed inspection. These inspections can be undertaken using magnetic particle or dye
penetrate testing to identify the presence of fatigue cracks.

3.2.3 Concrete structures
For concrete structures engineering inspections may involve undertaking a cover meter survey to determine the location, size and spacing of reinforcement. For extra certainty the reinforcement can be inspected by removing the cover concrete and exposing the reinforcement to determine its type.

Concrete cores and material testing of the concrete can be undertaken to determine its compressive strength and the level of carbonation and chlorides.

Half cell potential tests can be used to determine the propensity of corrosion to occur in the reinforcement.

4. Test loading
Test loading may be undertaken in the field or on prototypes. The type of test loading depends on the type of structure, its condition, understanding of the structure and costs. There are two main forms of load testing: static load testing and dynamic load testing.

4.1 Static load tests
With respect to static load testing, a range of options can be undertaken:
- Destructive load testing
- Static performance load testing
- Static proof load testing.

4.1.1 Destructive testing
Destructive load testing is the process of loading bridges or components to failure. Destructive load tests are rarely used on complete bridges due to the value of the bridges and the cost of testing. Most commonly the tests are undertaken on disused bridges or prototypes built and tested in laboratories.

Of most benefit, and at comparatively low cost to asset owners, is the destructive testing of bridge components. For example, a tensile test of reinforcement and coupons, pull-out tests on anchors and concrete compressive strength tests. These forms of testing are destructive to the samples but, if chosen from appropriate areas of the structures, have little or no effect on the structure’s capacity.

4.1.2 Static performance load testing
Static performance load testing is the process of loading structures within their elastic range. As the structures are not damaged during the process and as the level of load applied is comparatively low to the structure’s ultimate capacity, the cost of these types of tests are relatively low.

The simplest form of static load testing is to observe the passage of vehicles on a bridge. By observing the passage of vehicles it may be possible to detect regions of the bridge that have failed or are close to failing. In particular it may be possible to identify issues such as loose expansion joints or poorly seated bearings.

Of most benefit is the loading of structures with a known load and measuring the deflection response of a structure; in the case of railway bridges this is made relatively easy due to the locomotives weighing a substantial amount but with a relatively well understood level of loading (generally varying only with fuel intake). The purpose of the testing is to confirm the performance of the structure to the design models that have been created for it.

pitt&sherry has used this process successfully to better understand the capacity of timber bridges. For example, by deflection testing with a known load, the quality of timber members can be compared with that assumed in assessment. The testing can then be used to rapidly identify deficient members within a group of members.

pitt&sherry has also used strain gauging to measure the load distribution in Princes Bridge in Melbourne, as the support conditions for the spans were unclear due to the multiple supports per span.

4.1.3 Static proof load testing
This type of testing is comparatively expensive and involves taking loading on a structure to levels approaching the elastic limit of the structure.

This type of testing often involves placing kentledge on a truck to load levels far exceeding that of legal loads and has typically been confined to use by state road authorities due to the cost of the tests.

pitt&sherry has used static proof load testing on a pedestrian structure to confirm its load capacity prior to and after strengthening to confirm its capacity. As the structure was a pedestrian bridge the level of load required to test the structure was moderate, making this form of testing inexpensive for this type of structure.

4.2 Dynamic load testing
AS 5100 outlines the use of dynamic load testing to determine the dynamic amplification of load caused by vehicle structure interaction; however, for road bridges it is difficult to make much use of these types of tests to modify the amplification factor due to the range of types of vehicles using the structures. For rail bridges, however, it has been accepted that the amplification factor may be modified with the speed of vehicles.

pitt&sherry has dynamically tested a footbridge to determine its response to pedestrian excitation. Data collected included the natural frequency of the structure and the level of dampening for later use and comparison with structural models.

Low strain dynamic testing can be used on piles. ASTM D5882 covers the Standard test method for low strain impact integrity testing of deep foundations. Using this methodology on piles can assist in determining the physical dimensions of piles, such as length and cross-section. The test method, however, will not give information about the pile bearing capacity even though some authorities have used this method in an attempt to determine the capacity of their bridges. Should the capacity of piling be required then it may be estimated by locating pile markings indicating pile lengths, review of ‘as built’ or design drawings and then comparing this information with geotechnical information obtained from site.
5. Conclusion
The load capacity of bridges may be determined by analytical means or by load testing. Generally, analytical means are the cheapest methods.

The simplest form of analytical assessment is a generic load assessment but it doesn't provide information relating to a structure’s ‘as is’ capacity. With additional cost, field investigation can be undertaken along with detailed assessment in accordance with AS 5100 to determine both a structure’s ‘as new’ and ‘as is’ condition. AS 5100 presents such results in the form of load rating factors. For a successful assessment, it needs to be undertaken by an appropriately qualified and experienced bridge engineer. (This information can be obtained from the qualified list maintained by state road authorities.) The assessment should also use appropriate rating vehicles as well as the original design vehicle.

The load capacity of a structure may be determined by undertaking physical load testing, with the simplest and cheapest form being to observe the passage of vehicle on a structure. With increasing costs of testing, structures may then be instrumented and static performance testing undertaken. This form of testing is useful for the calibration of analytical models. If the ultimate strength of a structure is required then destructive tests can be used but these are often the most costly and generally restricted to use by state road authorities.

References

Australian Standards 2004, Bridge design part 7: rating of existing bridges.